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DCIEM CR 2001-087

Integrated Patrol Pack & Rucksack Development Phase III B Performance Testing of Suspension Components

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August 1999

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Integrated Patrol Pack and Rucksack Development Phase III B Performance Testing of Suspension Components for the CTS Rucksack

by

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PWGSC Contract No. W7711-7-7413/001/SRV

on behalf of
DEPARTMENT OF NATIONAL DEFENSE

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August , 1999

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Abstract

The relationship between large compressive loads applied to the surface of human skin and resulting tissue trauma such as inflammation (Kosiak, 1961), pressure sores (Scales, 1990), and nerve lesions (Mello et al , 1988, Brown, 1990) is well documented Holwijn (1990) recognized the importance of contact pressure magnitude and duration as contributing factors to the inflammation response of the skin and underlying tissue while using a personal Load Carriage System (LCS) Currently, there is no consensus regarding acceptable safe limits for average skin contact pressure at the shoulder, lower back, or hip. Based on recent work by Stevenson et al, (1995), contact pressure of 20 kPa is recommended as a threshold limit value for typical load carriage applications The purpose of this study was to compare and evaluate the anterior shoulder and axilla pressure distributions for three prototype shoulder strap designs, and the lower lumbar and iliac region pressure distributions under three waist belt designs, during simulated standard marching trials. Peak and average pressures were used to compare the prototype shoulder straps and waist belts Pressure distributions were examined to identify the location of design features that created peak pressures Several design characteristics were identified and evaluated based on these criteria. The key to reducing pressures in the axilla and shoulder region was to maintain the maximal contact area between the shoulder straps and the skin. For the waist belts, adapting the contact characteristics of the bottom edge on the lumbar pad to significantly reduce the occurrence of peak pressure zones within the lower lumbar region is recommended. Also, interference with the waist belt and the lower combat shirt pocket caused peak pressures to occur in the iliac region. Removing this interference should produce a more homogeneous pressure distribution beneath the waist belt

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1. INTRODUCTION

1.1 Background

The relationship between large compressive loads applied to the surface of human skin and resulting tissue trauma such as inflammation (Kosiak, 1961), pressure sores (Scales, 1990), and nerve lesions (Mello et al., 1988; Brown, 1990) is well documented. The mechanism of tissue damage is unclear; however, some researchers have hypothesized compromised lymphatic return, hydrostatic pressure gradients, and compromised interstitial transport processes as possible causes. It is likely that a combination of these interrelated mechanisms contribute toward degenerative responses in the skin and underlying tissue when a pressure is applied over a long enough duration (Mak et al., 1994). Holwijn (1990) recognized the importance of contact pressure magnitude and duration as contributing factors to the inflammation response of the skin and underlying tissue while using a personal Load Carriage System (LCS). With the trend of increasing volume and mass of load carriage systems (Parker, 1990), evaluation of the associated contact pressure distribution becomes critical.

Rucksack palsy, a paralysis of the brachial plexus at the level of the shoulder, is a relatively common pressure induced injury associated with excessive pressure from backpack shoulder straps (Bessen et al., 1987). Studies by Hargens et al. (1993) indicated nerve damage at pressures of 5 kPa with exposure of 3 hours. In muscle, pathological changes are observed at pressures of 9 kPa exposed for 2 hours, with a complete cessation of blood flow at 16 kPa (Kosiak, 1961). Sangeorzan et al. (1989) determined that compressive load producing contact pressures as low as 10 kPa can cause severe blood occlusion and a drop in the transcutaneous partial pressure of oxygen when applied to the surface of human skin. These studies suggest that the limit of exposure for an anatomical region will depend on the nature of the tissues involved. Stevenson et al., (1995) suggest that skin contact pressures should not exceed 14 kPa, and that the majority of users will report discomfort in the shoulder if the average contact pressure exceeds 20 kPa.

1.2 Rationale

Shoulder straps on military rucksacks must be designed with specific features and concerns that are not necessarily applicable to their civilian counterparts. A military rucksack must have the ability to quickly doffed and must not interfere with other items of the load carriage system such as the webbing or load carriage vest. Although civilian rucksack shoulder straps do not need to meet all of the functional requirements of a military rucksack, they do have several features that could be adopted to minimize the risk of injury associated with load carriage in the military. Civilian rucksacks generally possess more contoured shoulder straps that curve over the clavicle to redirect the straps' line of force away from the axilla and have thicker padding than their military counterparts (Stevenson et al., 1995).

Three prototype shoulder strap designs with different strap contours that do not interfere with other LCS articles are available to be tested with the Ostrum Prototype Pack K1. By examining the resulting pressure distribution on the anterior shoulder and axilla, the shoulder strap curvature and design features can be assessed. An optimal shoulder strap design can then be achieved by adopting design features that minimize the peak and average pressures at the anterior shoulder and axilla.

Similarly, by determining the peak pressures and pressure distribution under three waist belt designs, design features can be evaluated and a superior waist belt design can be achieved.

1.3 Objective

The purpose of this study is to compare and evaluate the anterior shoulder and axilla pressure distributions for three prototype shoulder strap designs, and the lower lumbar and iliac region pressure distributions under three waist belt designs, during simulated standard marching trials.

2. METHODOLOGY

2.1 Protocol

Each set of prototype shoulder straps was fastened to the Ostrum Prototype Pack K1 for the testing procedure. The pack was then placed on the Load Carriage Simulator (LCS), a 50th

percentile manikin torso with computer controlled pneumatic actuators that can be programmed to replicate tasks such as level walking. The manikin torso was rotated forward to balance the posterior moment created by the pack, and the shoulder straps and waist belt were tightened to standard test values of 60 N and 40 N respectively. A standard marching trial with a cadence of 1.8 Hz and a displacement of +/- 25.4 mm was conducted and pressure measurements in the anterior shoulder and axilla region (Fig. 1a) were recorded.

The three waist belt designs were assessed and compared by using the same LCS protocol on three separate rucksacks. F-scan™ pressure sensors were located in the lower lumbar and iliac regions (Figure 1b).

Peak pressure, average pressure, contact area, average force, and a Pressure Distribution Index (PDI = peak pressure/average pressure) were determined and used to compare the prototype shoulder straps and three waist belts. The pressure distribution was examined to identify the location of design features that created peak pressures.

F-Scan ™ pressure sensor technology (Tekscan Incorporated) was used to acquire contact pressure data on the manikin. The F-Scan™ system uses a matrix of force sensitive resistors, which are arranged in a rectangular pattern and contained between two flexible polyester plastic sheets. When the thin polymer foil in an element is compressed, the voltage passed across the element changes. This change is sensed by system software, and is recorded as a load normal to the sensor surface, based on individual calibration for each sensor. Information is transferred to the computer through a signal processing unit and cable to a computer card. This information can be replayed in 'movie' format, which can give a dynamic measurement of force, average and peak pressures, active area, or duration of contact. Previous testing at Queen's (DCIEM Contract #W7711-4-7225/01-XSE) has found the F-Scan™ system standard error of the mean to be 9.6 % for average pressures and 14 % for peak pressures. Also, use of the sensors on a curved surface leads to a 9% standard error of the mean for average pressure results (McNiel, 1996).

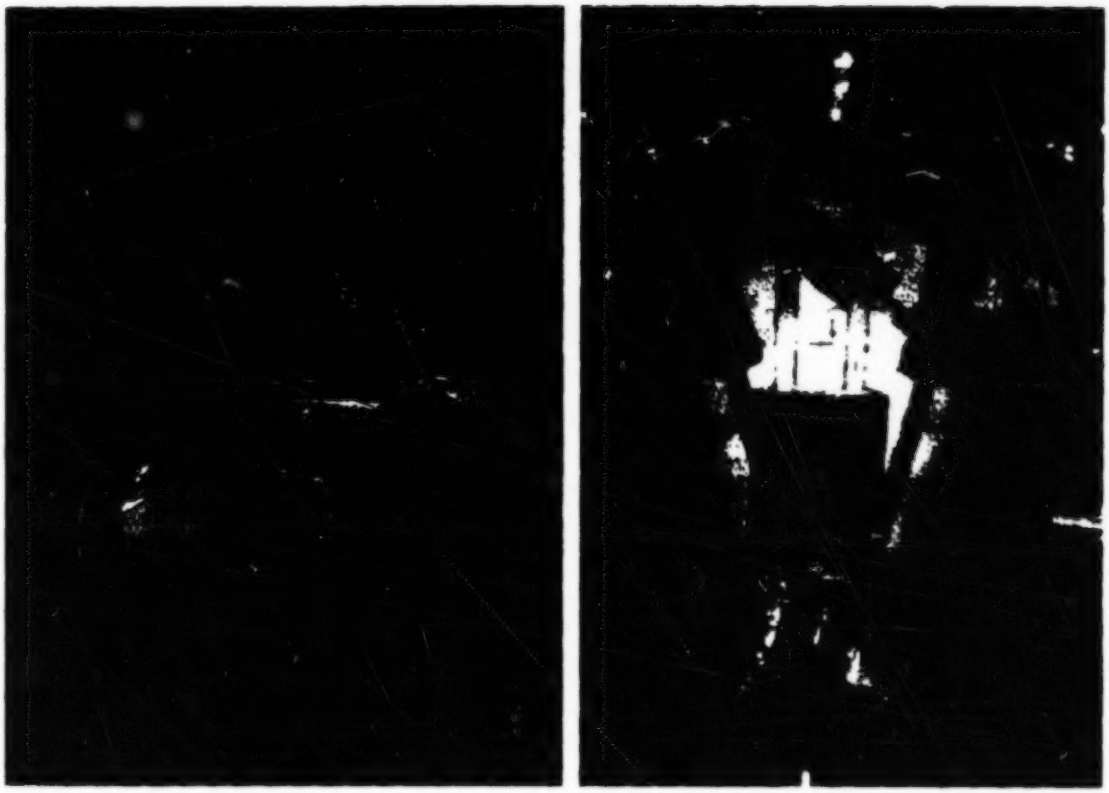

Figure 1. a) Orientation of axilla and anterior shoulder F-Scan pressure sensors. b) Orientation of lower lumbar and iliac F-Scan pressure sensors.

2.2 Prototype Shoulder Strap Descriptions

Three prototype shoulder strap designs (Figures 1-4) were examined in this study:

A. The original shoulder straps supplied with K1 prototype rucksack for November 25-27, 1997 Rucksack Focus Group. The lower shoulder strap adjustment buckle was clear of the shoulder strap padding. This was the longest prototype design examined.

B. This shoulder strap design had a sharp curve in the axilla region (radii of curvature approximately 5.5 cm). The lower shoulder strap adjustment buckle was backed with shoulder strap padding and the length was the shortest of the three designs.

C. This design had the sharpest axilla curve (radii of curvature approximately 9 cm). The lower shoulder strap adjustment buckle was clear of shoulder strap padding and the length of the straps was in between that of prototypes A and C.

Figure 2. Comparison of the shape of three prototype shoulder straps: A (top), B (middle), and C (bottom).

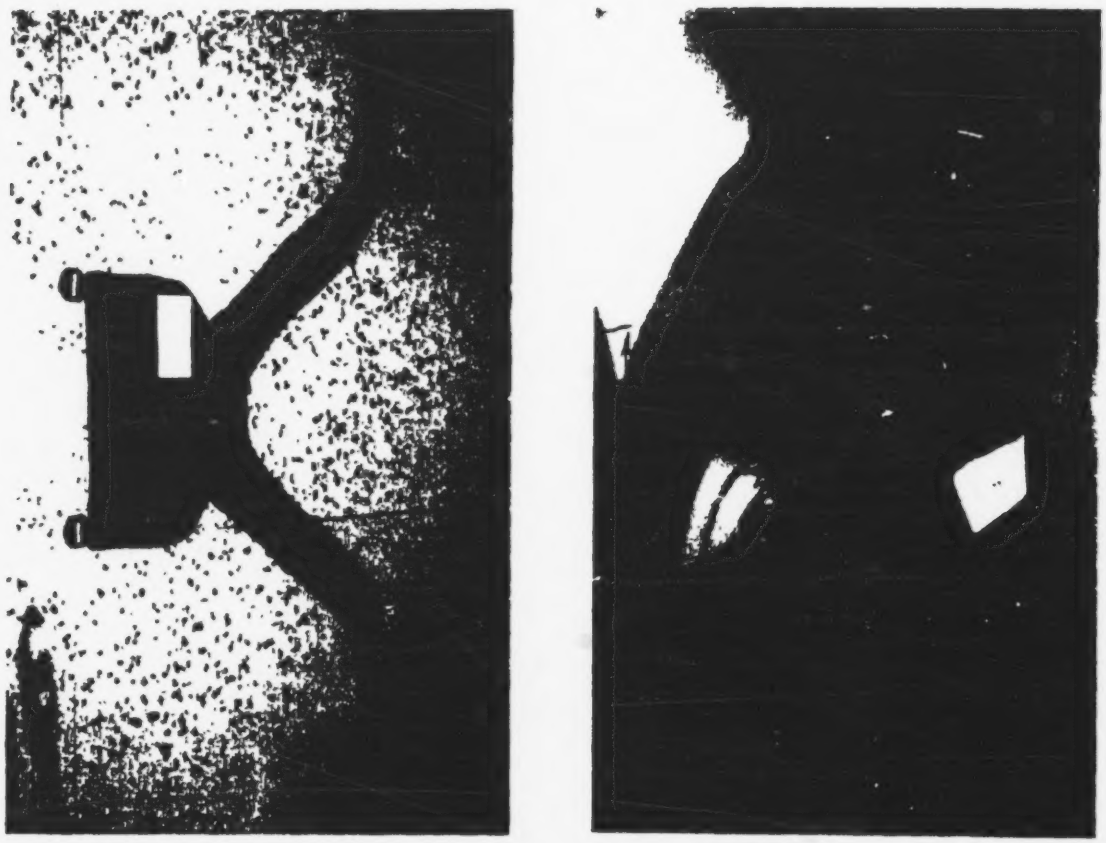

Figure 3. Prototype shoulder strap A: on floor (left) and *in-situ* (right).

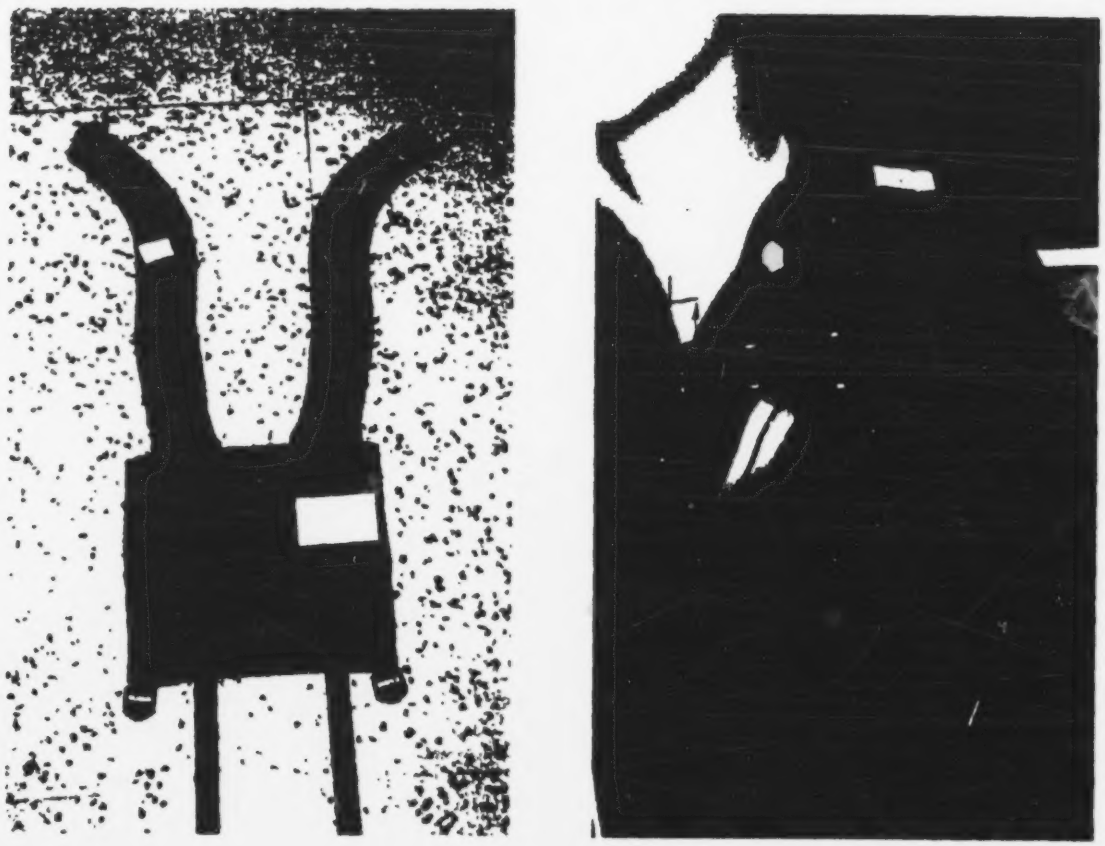

Figure 4. Prototype shoulder strap B: on floor (left) and *in-situ* (right).

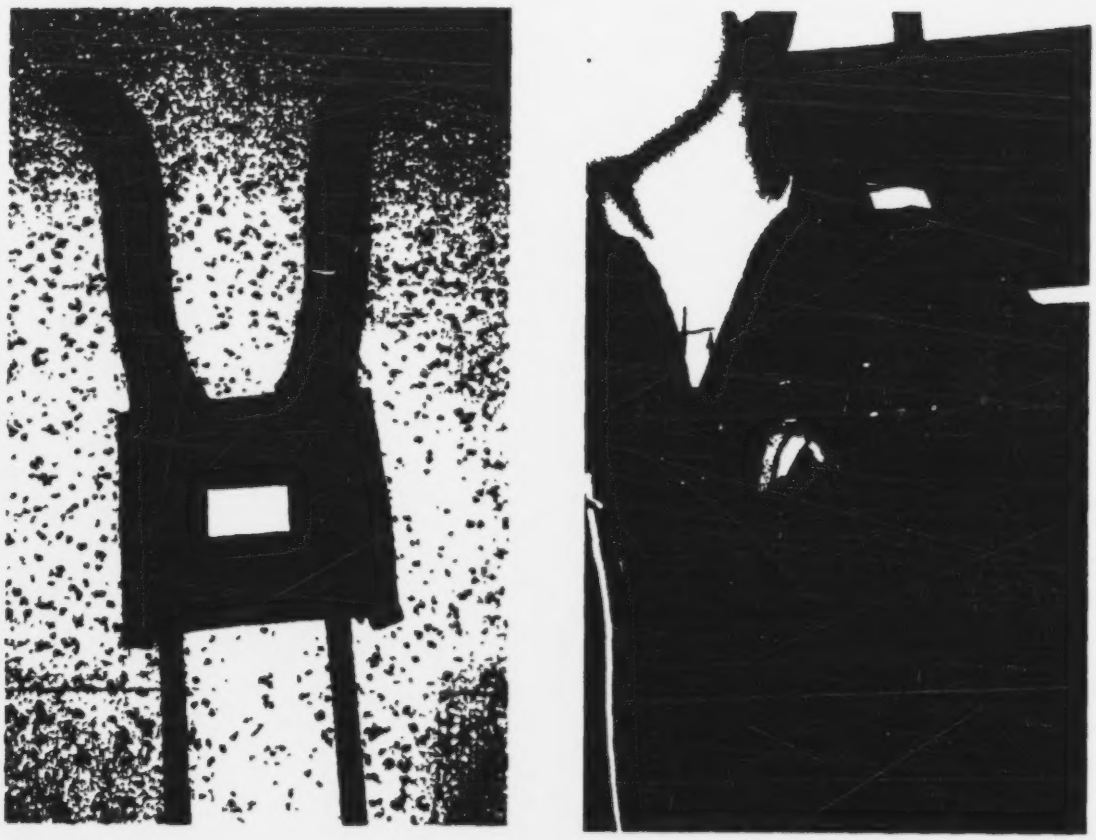

Figure 5. Prototype shoulder strap C: on floor (left) and *in-situ* (right).

2.3 Waist Belt Designs

The waist belts examined in this study were as follows:

A. Ostrum Prototype Pack K1 waist belt

B. Ostrum Prototype Pack M1 waist belt

C. Dana Designs Arc Flex Astral Plane waist belt

3. RESULTS

3.1 Pressure values for prototype shoulder straps.

Table 1 contains a summary of pressure values recorded during the testing of the three shoulder strap samples during simulated level walking. The information presented consists of the average pressure, the peak pressure, the ratio of peak pressure to average pressure (pressure differential index (PDI)), the force experienced by the wearer, and the total contact at that location during one recording sample (10 seconds).

Table 1. Pressure values from dynamic shoulder strap testing.

Sample	Location	Peak Pressure (kPa)	Average Pressure (kPa)	Contact Area (cm^2)	PDI	Force (N)
A	Shoulder	32.4	15.4	35.5	2.1	54.6
	Axilla	54.9	23.4	30.6	2.3	71.6
B	Shoulder	18.5	12.8	25.8	1.4	33.0
	Axilla	70.9	26.8	27.4	2.6	73.4
C	Shoulder	18.5	12.1	46.8	1.5	56.6
	Axilla	45.7	24.5	27.4	1.9	67.1

3.2 Shoulder Strap observations and pressure distribution profiles

Prototype A

1. Poor fit was observed between prototype A shoulder straps and the manikin with lateral twisting causing liftoff of the medial edge on both straps. This resulted in relatively low contact pressure on the anterior shoulder.

2. The prototype A shoulder strap design also placed the upper shoulder strap adjustment buckle deep (more posterior) in the armpit. High pressure (55 kPa) occurred where 1 inch webbing and padding curve under the shoulder into the axilla.

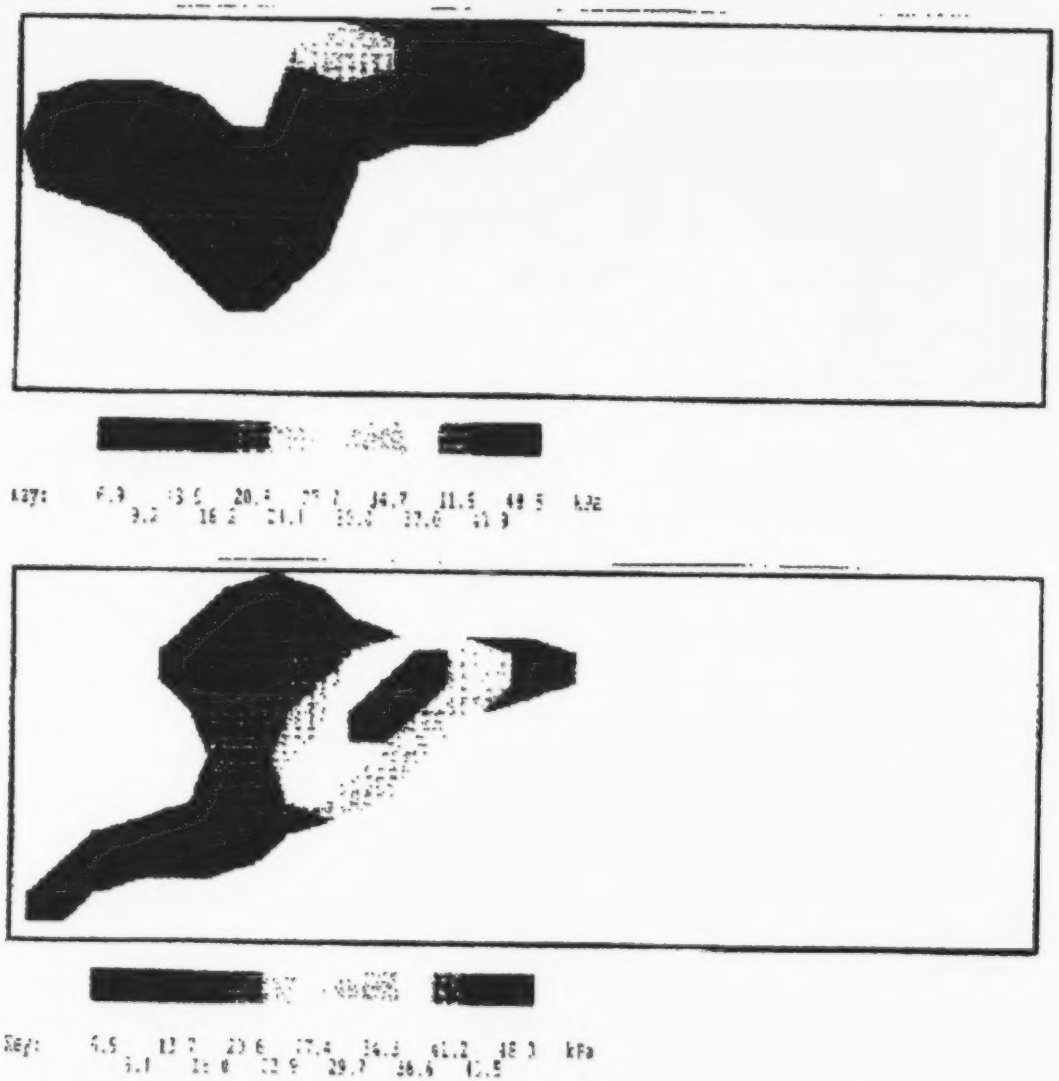

Figure 6. Anterior shoulder (top) and axilla (bottom) pressure profiles for shoulder strap A.

Prototype B

1. Lateral twisting (rollover) of shoulder straps was reduced compared to prototype A due to the horizontal origin of the shoulder straps at back panel.

2. The load lifter strap tended to fold over itself due to the large lateral distance between the shoulder strap tri-glide (load lifter origin) and the adjustment buckle on the top of the stay (load lifter insertion). This large lateral displacement occurred over a small posterior and superior displacement, forcing the strap to double back over itself. Since the twisting occurs at the tri-glide, this did not appear to effect the ability to tighten the load lifter.

3. The position of the lower attachment point on the pack causes the ladder lock on the end of the shoulder strap to twist. This twisting pushes one corner of the Ladderlock ™ into the padding behind it, producing a high-pressure site (70 kPa) at the axilla.

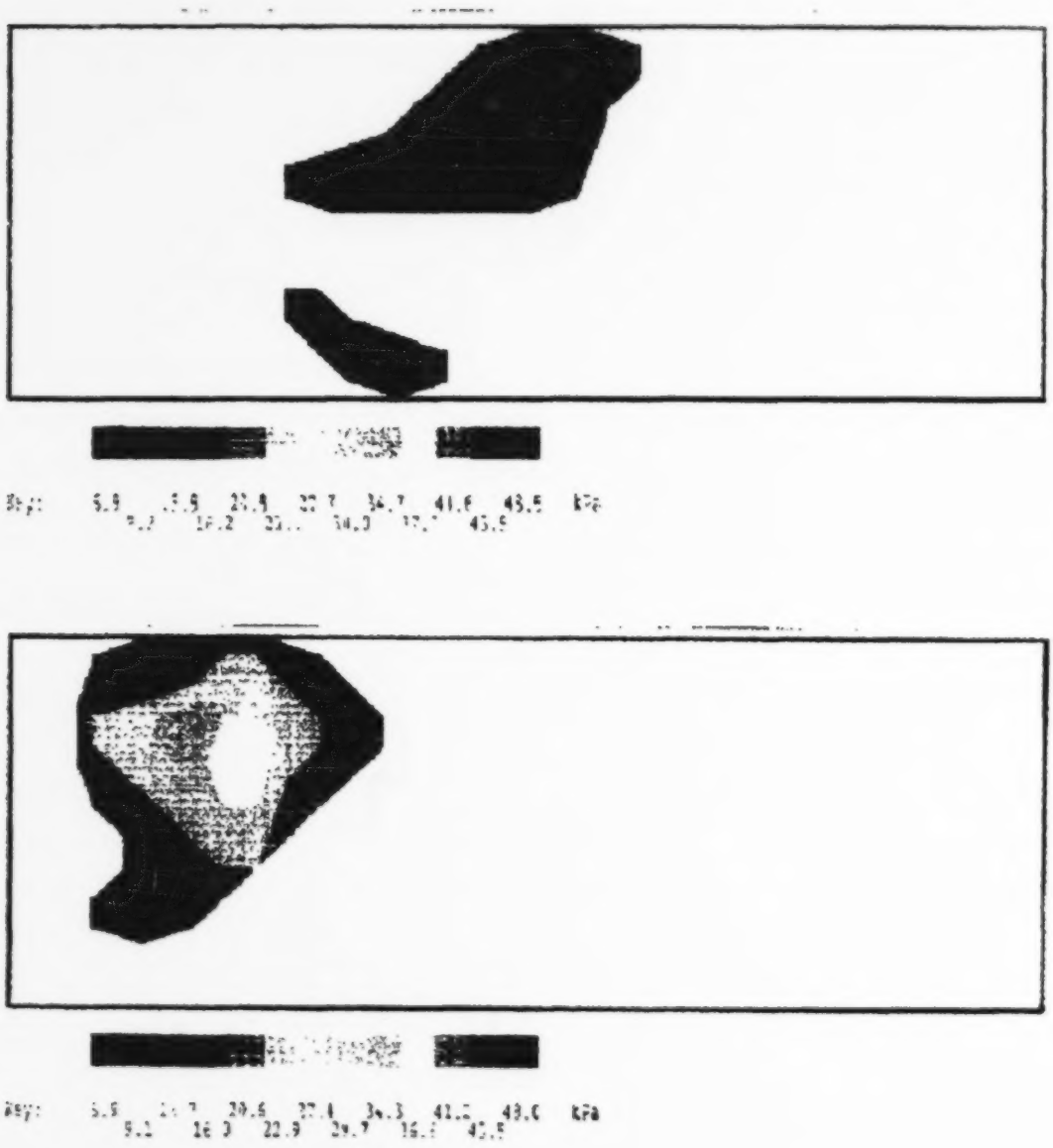

Figure 7. Anterior shoulder (top) and axilla (bottom) pressure profiles for shoulder strap B

Prototype C

1. Lateral twisting (rollover) of shoulder straps was reduced with the horizontal origin on the back panel. However, straps now seemed more flat horizontally and did not seem to follow natural lateral slope of shoulder as well as B. Good average pressures and large a contact were present on the medial edge of the shoulder straps at the neck.

2. The load lifter straps still twisted over themselves due to the breadth of the attachments on the shoulder stays (see Sample B). This factor did not appear to effect the ease of use or the capability of the load lifter.

3. The length of the shoulder strap padding extended into the armpit approximately 2.5 cm further than Sample B. This increase caused a reduction in functional mobility for subject. (Hands together in front and hands together overhead.) A high-pressure (45 kPa) region occurred where the 1 inch webbing and the padding curve around the pectoral and into the armpit. The body of the person acts as a fulcrum that the shoulder strap changes direction over.

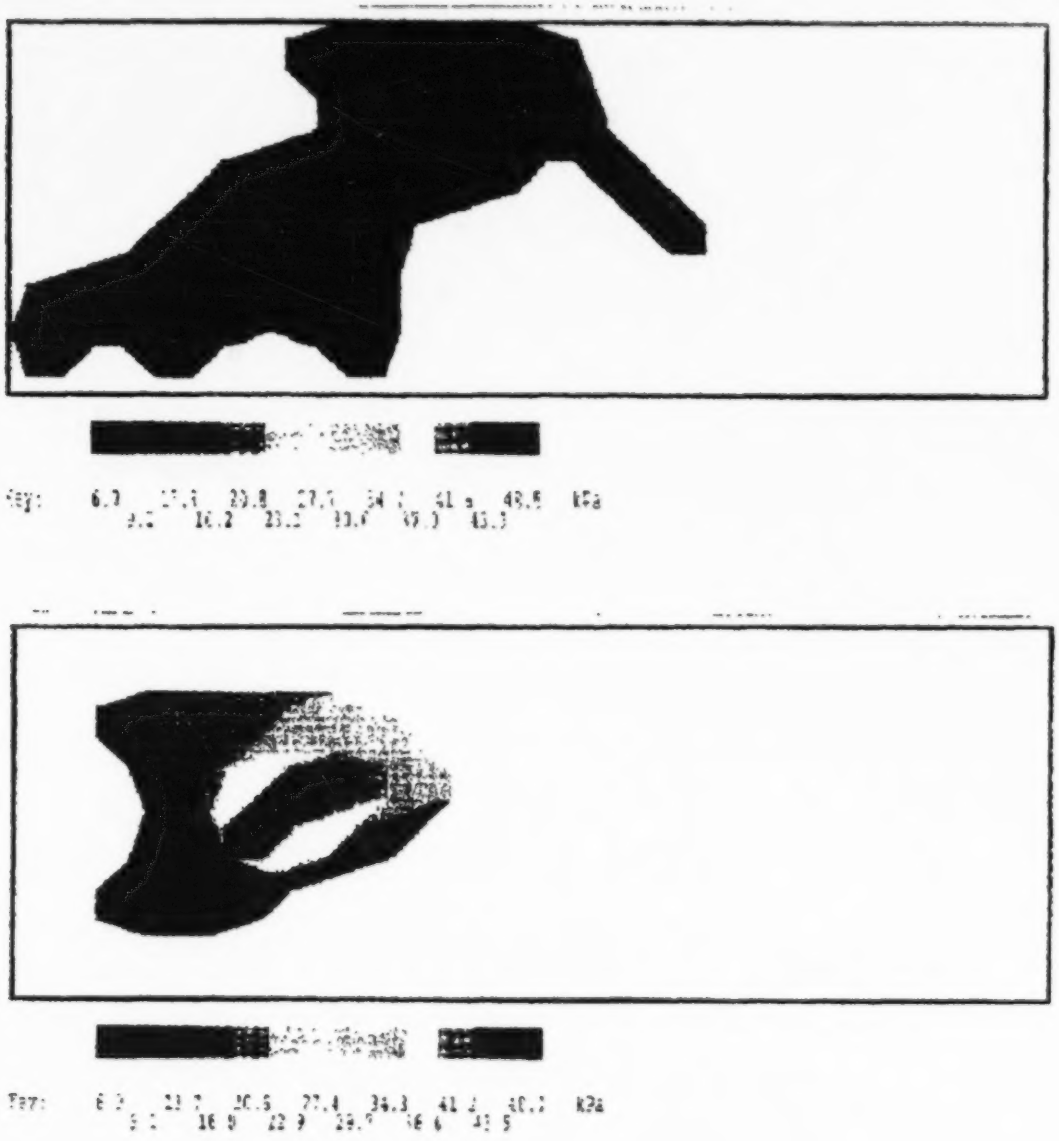

Figure 8. Anterior shoulder (top) and axilla (bottom) pressure profiles for shoulder strap C

3.3 Pressure values for waist belts.

Table 1 contains a summary of the pressure values recorded during the testing of the three waist belt designs during simulated level walking.

Table 1. Pressure values from dynamic waist belt testing.

Sample	Location	Peak Pressure (kPa)	Average Pressure (kPa)	Contact Area (cm^2)	PDI	Force (N)
A	Lower Lumbar	15.1	12.8	6.5	1.2	8.3
	Iliac Crest	22.1	19.0	3.2	1.2	6.1
B	Lower Lumbar	24.1	15.5	19.4	1.6	30.1
	Iliac crest	15.4	13.1	9.7	1.2	12.7
C	Lower Lumbar	30.1	18.0	45.2	1.7	81.4
	Iliac Crest	38.7	22.0	22.3	1.8	49.7

3.4 Waist belt observations and pressure distribution profiles

Waist Belt A: Ostrum Prototype Pack K1

1. The only pressure evident in the lower lumbar region occurred at the bottom edge of the lumbar padding.

2. The peak pressure occurring on the contour plot of the iliac region was a result of the seam at the top corner of the waist pocket on the combat shirt, which was trapped underneath the hip belt.

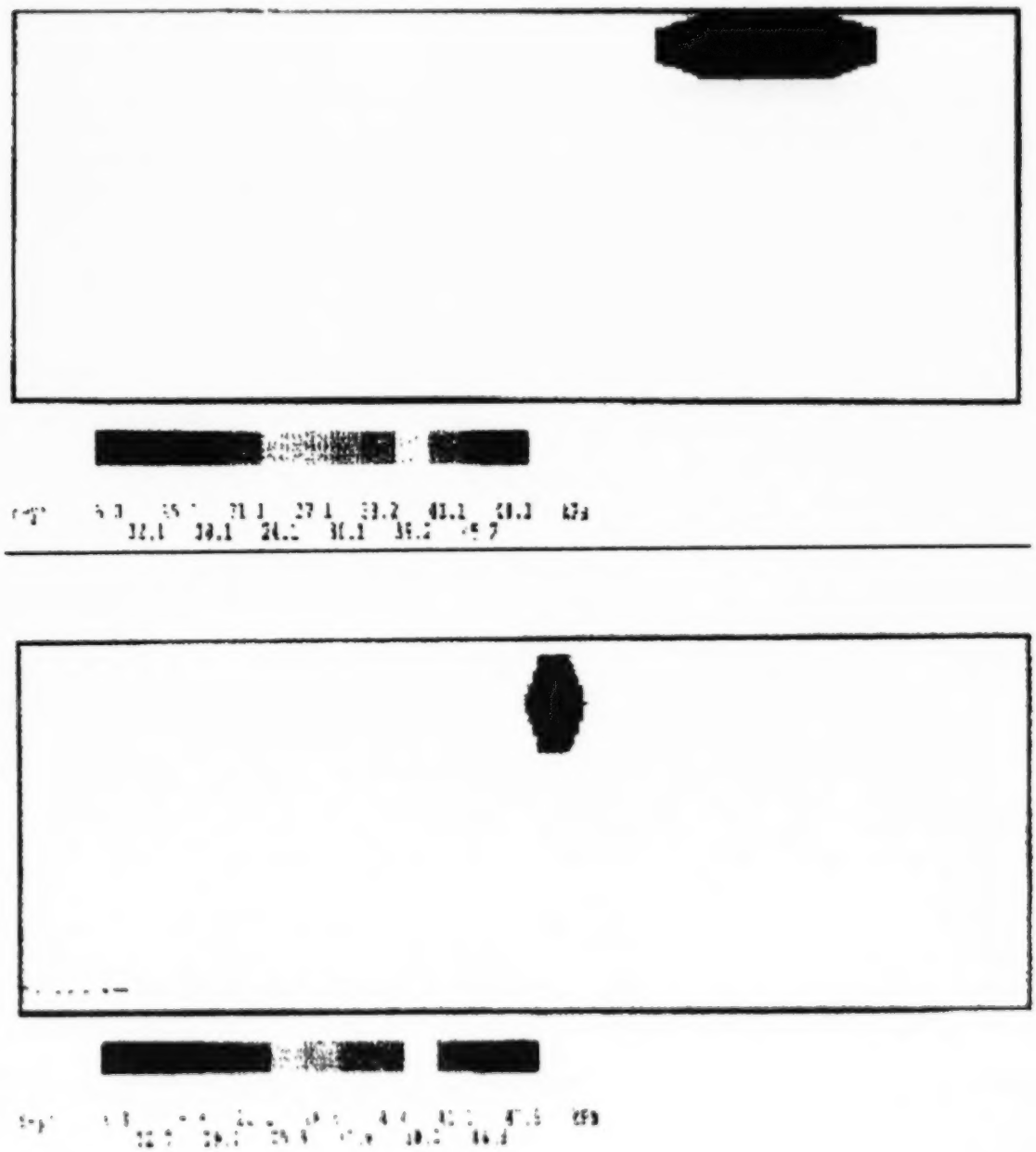

Figure 9. Lower Lumbar (top) and Iliac (bottom) pressure profiles for waist belt A.

Waist Belt B: Ostrum Prototype Pack M1

1. The bottom edges of the lumbar pad caused regions of increased pressure visible on the contour plot of the lower lumbar region.

2. The pressure map of the iliac region revealed two pressure peak locations corresponding to the edge of the hip belt padding, and the entrapment of the top corner seam of the combat shirt lower pocket.

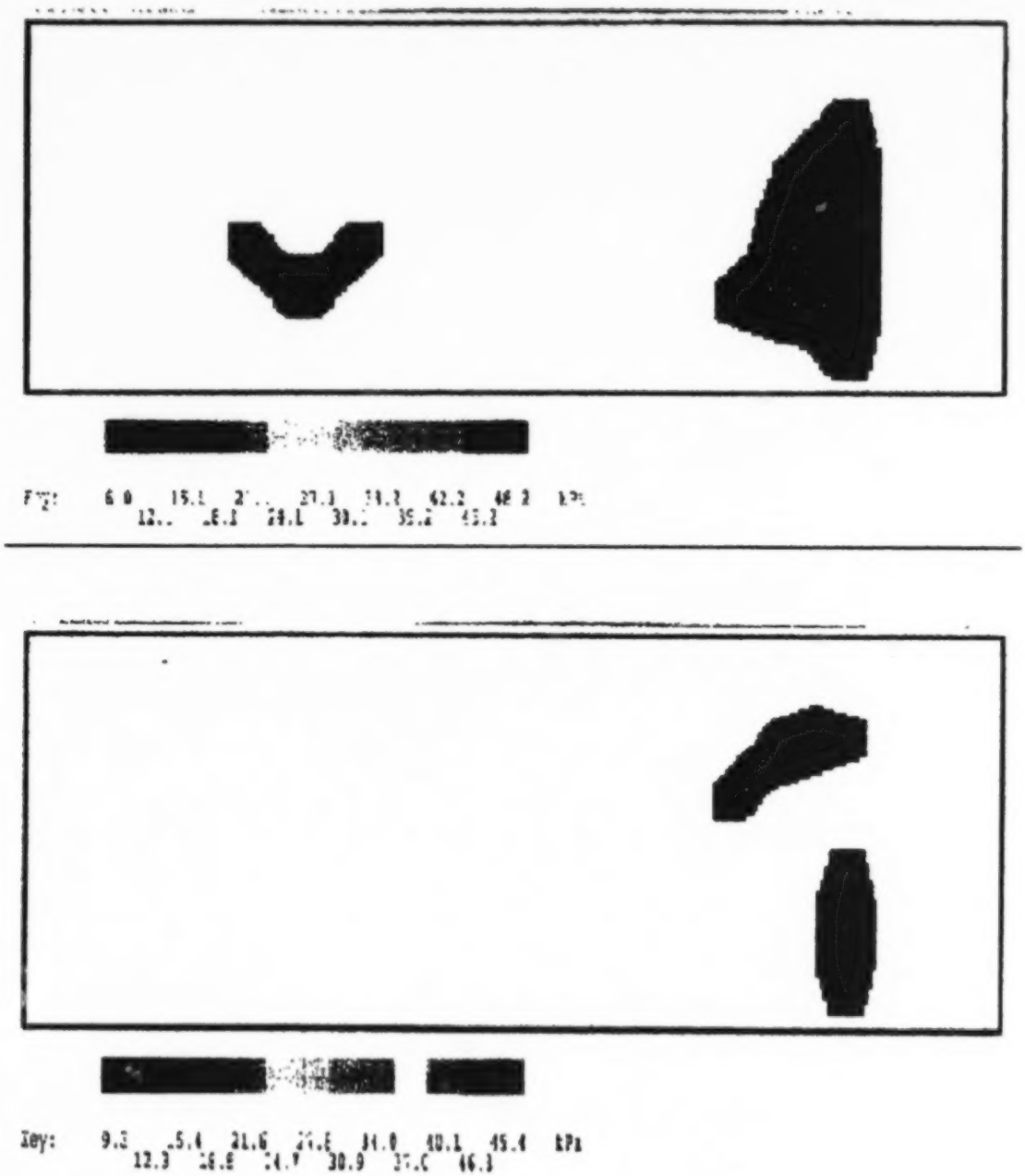

Figure 10. Lower Lumbar (top) and Iliac (bottom) pressure profiles for waist belt B.

Waist Belt C: Dana Designs Arc Flex Astral Plane

1. The contact areas shown in the contour plot of the lower lumbar region coincide with the juncture of the lumbar and hip belt padding over the posterior aspect of the sacrum.

2. Peak pressure regions on the pressure map of the iliac crest occur along the iliac crest beneath the waist belt.

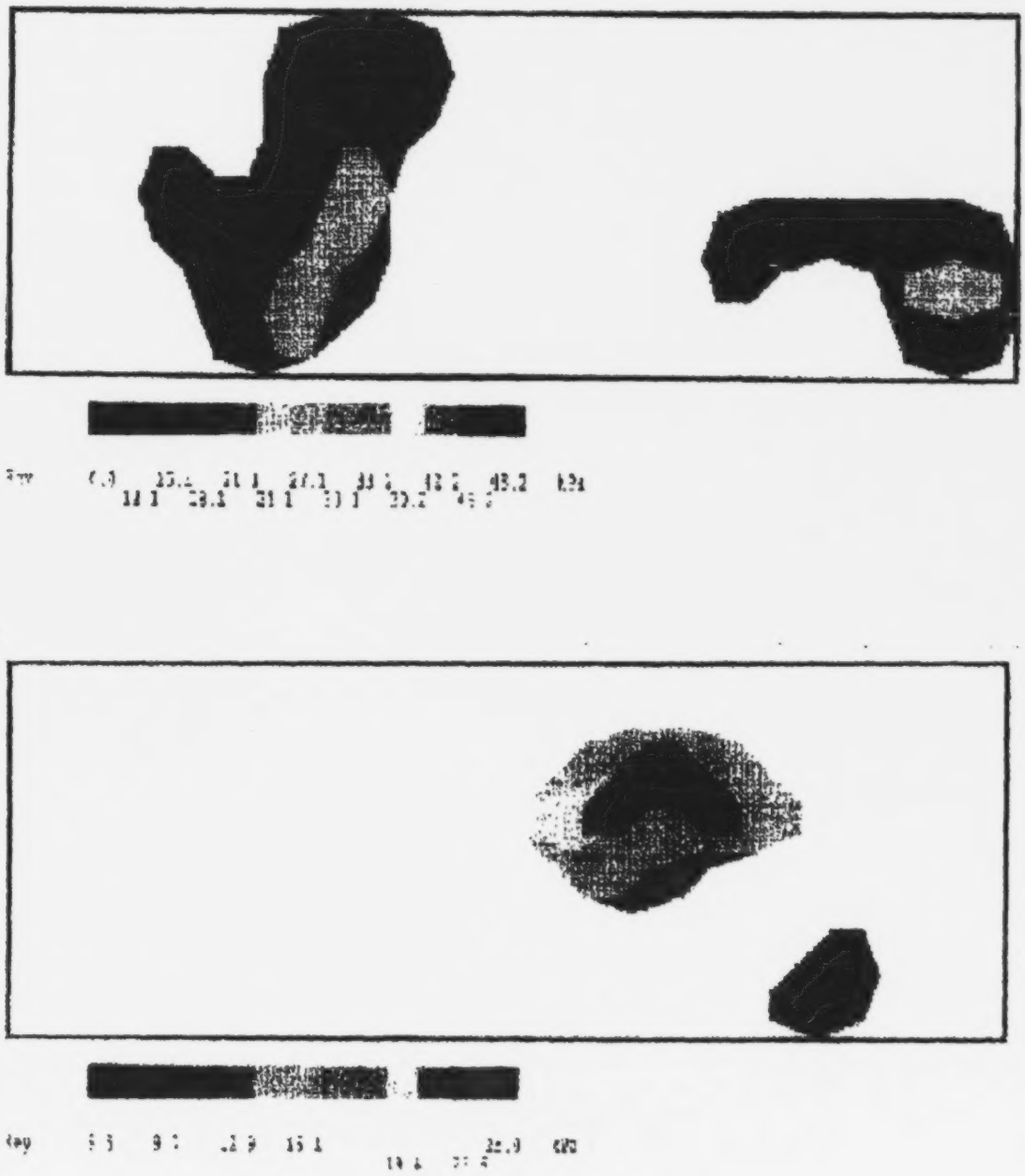

Figure 11. Lower Lumbar (top) and Iliac (bottom) pressure profiles for waist belt C.

4. DISCUSSION

4.1 Average Contact Pressures

Currently, there is no consensus regarding acceptable safe limits for average skin contact pressure at the shoulder, lower back, or hip. An average pressure of 14 kPa is presently recommended as the maximum value for exposures that exceed 8 hours in order to prevent skin necrosis due to blood occlusion. Previous studies by this laboratory have indicated that average contact pressures at the shoulder which exceed 20 kPa will lead to discomfort in the neck and shoulder region in 95% of soldiers. This value is therefore recommended as a threshold limit value for typical load carriage applications.

Average contact pressures of the Anterior Shoulder and Axilla.

All average contact pressures of the anterior shoulder were below the 20 kPa threshold. The prototype B and C shoulder straps did however improve on the prototype A design by reducing the anterior shoulder pressure measures by approximately 20%. Although all three prototypes produced axilla pressure values above the recommended threshold, prototypes A and C generated lower pressures than B. Overall, the prototype C shoulder straps exhibited the most favorable average pressure results.

Waist Belt Average Pressures

Waist belt designs A (Ostrum Prototype Pack K1) and B (Ostrum Prototype Pack M1) produced average contact pressures in the iliac region that were below the 20 kPa threshold whereas waist belt C (Dana Designs Arc Flex Astral Plane) generated measures that were slightly higher than 20 kPa. In the lower lumbar region, all three waist belt designs produced average pressures within the recommended threshold, however waist belt A produced the lowest average contact pressure.

4.2 Peak Contact Pressures

The sensitivity of human skin to instantaneous peak pressures varies widely with the characteristics of the applied pressure and the anatomy of the region under consideration. A pressure value of 120 kPa is considered to be a conservative threshold limit value for peak pressures in the regions of the shoulder, hip and waist.

Peak Contact Pressures of the Anterior Shoulder and Axilla

All peak pressures reported in the axilla and anterior shoulder regions (18.5-70.9 kPa) were well below the conservative threshold limit of 120 kPa. The peak pressure that occurs in prototype B corresponds to twisting of the shoulder strap, which forces the Ladderlock™ to be pressed into the shoulder strap padding.

Peak Contact Pressures of the Lower Lumbar and Iliac regions

All peak pressures reported in the axilla and anterior shoulder regions (18.5-70.9 kPa) were well below the conservative threshold limit of 120 kPa.

4.3 Conclusions

Prototype Shoulder Strap Evaluation

1. Both B and C prototypes have improved the strap design over prototype A with respect to anterior shoulder pressure measures and prototypes A and C produce superior axilla pressure measurements.

2. The key to reducing pressures in the axilla and shoulder regions appears to be maintaining the maximal area in contact between the shoulder straps and the skin (i.e. avoid twisting of the shoulder straps).

3. In prototype B, placing the ladderlock on top of the padding, about 4 cm higher on the body positioned it at this fulcrum point and accentuated the pressure point load.

Waist Belt Design Evaluation

1. Adapting the contact characteristics of the bottom edge on the lumbar pad to significantly reduce the occurrence of peak pressure zones within the lower lumbar region is recommended.

2. Interference with the waist belt and the lower combat shirt pocket caused peak pressures to occur in the iliac region. Removing this interference should produce a more homogeneous pressure distribution beneath the waist belt.

3. The A and B waist belts (on the Ostrum Prototype Packs K1 and M1) produced preferable average pressures and pressure distributions to the C waist belt (on the Dana Designs Arc Flex Astral Plane).

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DOCUMENT CONTROL DATA SHEET

1a. PERFORMING AGENCY	2. SECURITY CLASSIFICATION
Queen's University, Kingston, Ontario	UNCLASSIFIED Unlimited distribution -
1b. PUBLISHING AGENCY	
DCIEM	

3. TITLE

(U) Integrated patrol pack & rucksack development phase III B performance testing of suspension components

4. AUTHORS

R.A. Whiteside J.B. Doan S.A. Reid J.T. Bryant J.M. Stevenson

5. DATE OF PUBLICATION	6. NO. OF PAGES
August 1 , 1999	31

7. DESCRIPTIVE NOTES

8. SPONSORING/MONITORING/CONTRACTING/TASKING AGENCY
Sponsoring Agency:
Monitoring Agency:
Contracting Agency :
Tasking Agency:

9. ORIGINATORS DOCUMENT NO.	10. CONTRACT GRANT AND/OR PROJECT NO.	11. OTHER DOCUMENT NOS.
Contract Report 2001-087	W7711-7-7413/001/SRV	

12. DOCUMENT RELEASABILITY

Unlimited distribution

13. DOCUMENT ANNOUNCEMENT

Unlimited announcement

14. ABSTRACT

(U) The relationship between large compressive loads applied to the surface of human skin and resulting tissue trauma such as inflammation (Kosiak, 1961), pressure sores (Scales, 1990), and nerve lesions (Mello et al., 1988; Brown, 1990) is well documented. Holwijn (1990) recognized the importance of contact pressure magnitude and duration as contributing factors to the inflammation response of the skin and underlying tissue while using a personal Load Carriage System (LCS). Currently, there is no consensus regarding acceptable safe limits for average skin contact pressure at the shoulder, lower back, or hip. Based on recent work by Stevenson et al, (1995), contact pressure of 20 kPa is recommended as a threshold limit value for typical load carriage applications. The purpose of this study was to compare and evaluate the anterior shoulder and axilla pressure distributions for three prototype shoulder strap designs, and the lower lumbar and iliac region pressure distributions under three waist belt designs, during simulated standard marching trials. Peak and average pressures were used to compare the prototype shoulder straps and waist belts. Pressure distributions were examined to identify the location of design features that created peak pressures. Several design characteristics were identified and evaluated based on these criteria. The key to reducing pressures in the axilla and shoulder region was to maintain the maximal contact area between the shoulder straps and the skin. For the waist belts, adapting the contact characteristics of the bottom edge on the lumbar pad to significantly reduce the occurrence of peak pressure zones within the lower lumbar region is recommended. Also, interference with the waist belt and the lower combat shirt pocket caused peak pressures to occur in the iliac region. Removing this interference should produce a more homogeneous pressure distribution beneath the waist belt.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U)

#516237

CA011663